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Improved dq-axes Model of PMSM Considering Airgap Flux Harmonics and Saturation

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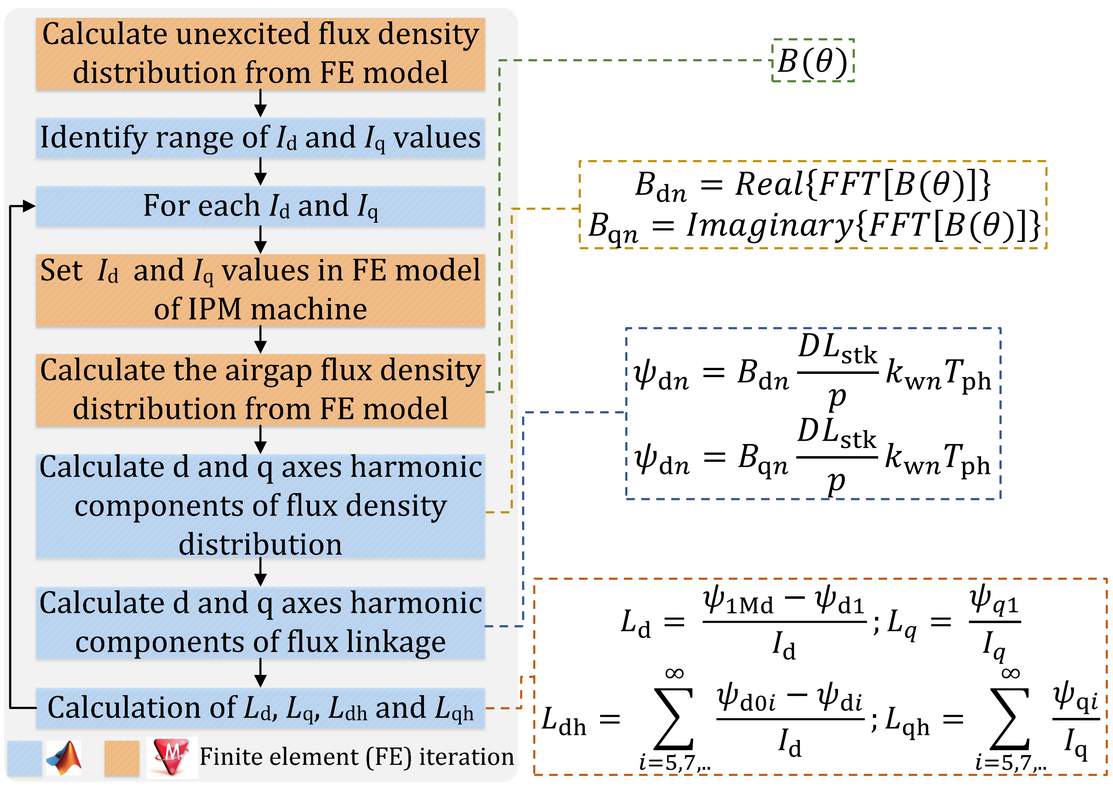
Summary

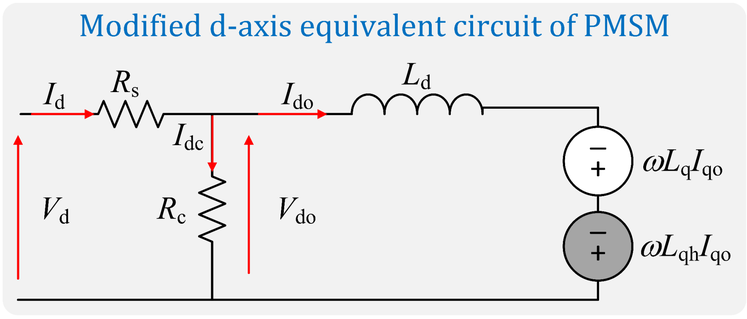
The classical dq-axes model of permanent magnet synchronous machines (PMSM) uses linear approximation. This was not an issue in earlier versions of PMSM drives because they mostly used surface magnet motors. With the arrival of interior permanent magnet (IPM) machines, which use reluctance torque along with magnet torque, the accuracy of linear models are found to be insufficient. In this work, the effect of air gap flux harmonics is included in the classical model of PMSM using *d* and *q*-axes harmonic inductances. Further, a method has been presented to assess the effect of saturation and cross-saturation on constant torque curves of PMSM. Two interior permanent magnet motor with two different rotor topologies and different specifications are designed to evaluate the effect of saturation on synchronous and harmonic inductances, and operating points of the machines.

Improved dq-axes circuit and estimation of circuit parameters

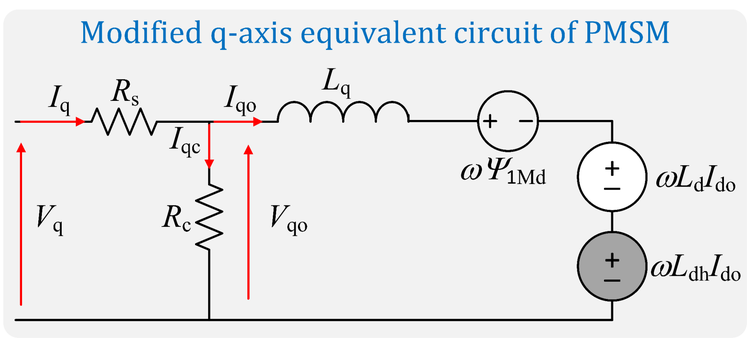
Estimation of fundamental and harmonic inductances from FE model



Modified d-axis equivalent circuit of PMSM



Modified q-axis equivalent circuit of PMSM



Equations for modified equivalent circuit of PMSM

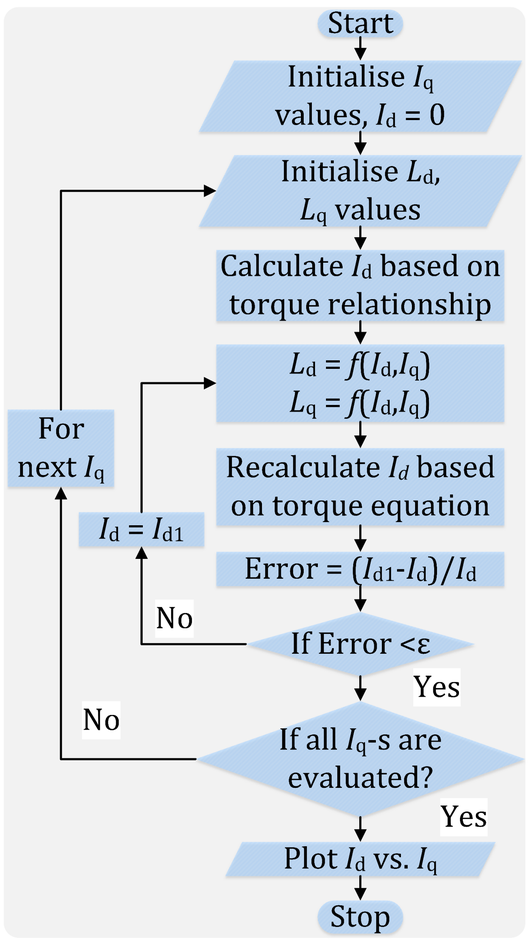
$$V_{do} = -\omega L_q I_{q0} - \omega L_{qh} I_{q0}$$

$$V_{qo} = \omega\psi_{1Md} + \omega L_d I_{d0} + \omega L_{dh} I_{d0}$$

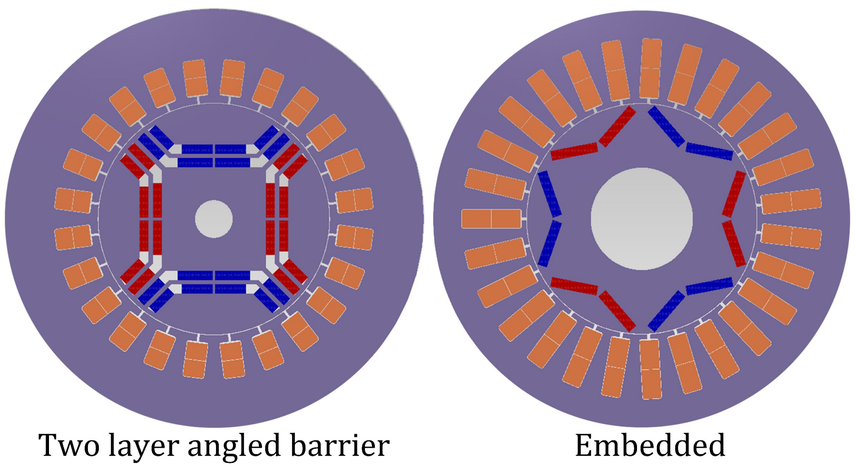
$$V_d = I_d R_s + V_{d0}$$

$$V_q = I_q R_s + V_{q0}$$

Estimating effect of saturation on operating point of PMSM



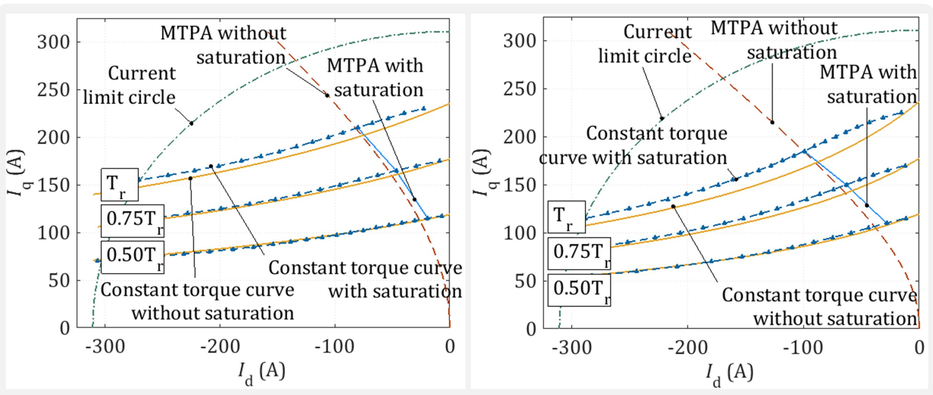
Motor topology and design details



Specification and dq-axes equivalent circuit parameters

Rotor topology	Two layer angled barrier	Embedded
Rated power (kW)	125	75
Rated speed (rpm)	3275	3055
Full load torque (Nm)	364	233
Full load RMS line voltage (V)	315	308
Full load RMS phase current (A)	319	220
Outer diameter of stator (mm)	276	300
Stack length of stator (mm)	193	281
Magnet flux linkage (Wb-turns)	0.24	0.17
d-axis inductance at full load (mH)	0.34	0.47
q-axis inductance at full load (mH)	0.79	1.39
Core loss at full load (W)	830	3240
Core loss resistance (Ω)	120	29

Effect of saturation on operating point of PMSM

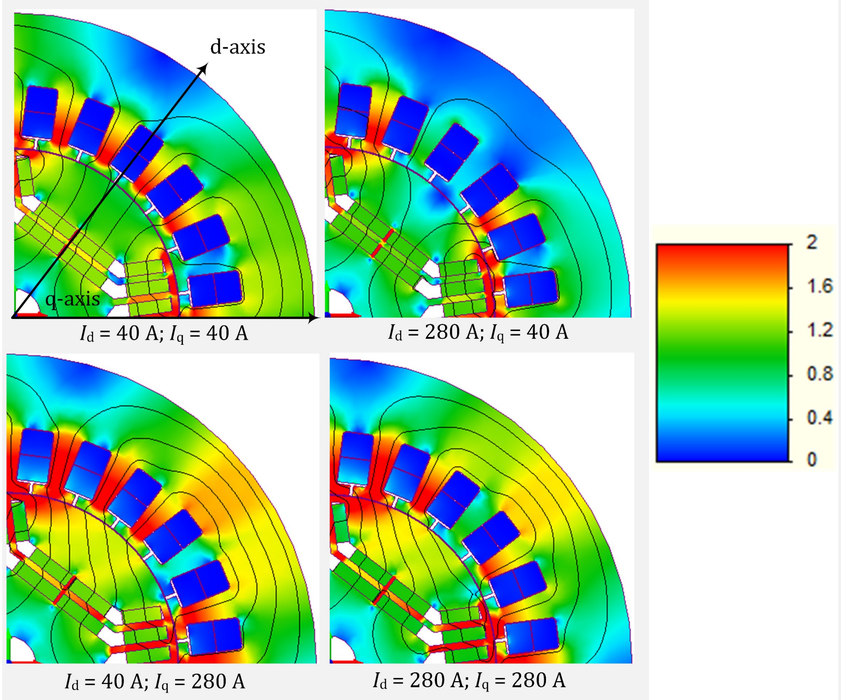


Two layer angled barrier IPM machine | Embedded IPM machine

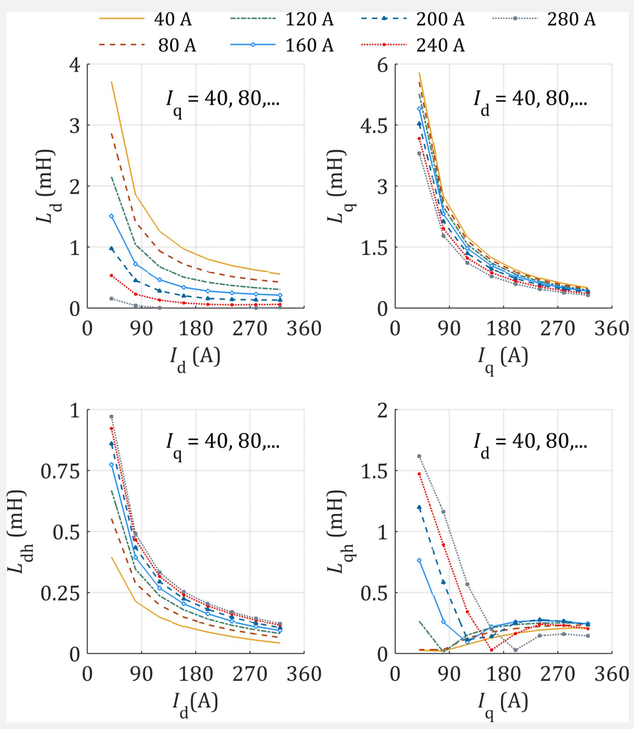
Variation of synchronous and harmonic inductances with dq-axes currents

Two layer angled barrier

Flux density plots for different I_d and I_q

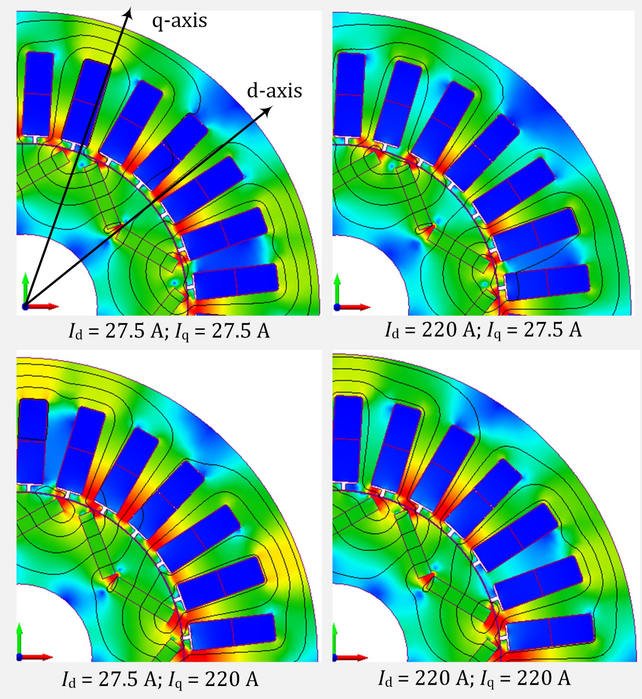


Synchronous and harmonic inductance variation with I_d and I_q



Embedded

Flux density plots for different I_d and I_q



Synchronous and harmonic inductance variation with I_d and I_q